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ABSTRACT

This second in a series of eight modules for a course titled Metrology dscribes fixed gages, dividers, calipers, vernier and dial calipers, and micrometers. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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COURSE 27 METROLOGY

MODULE 27-2 Fixed Gages, Dividers, Calipers and Micrometers

CE 024 254

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 27 METROLOGY

Module 27-1	Fundamentals of Metrology
Module 27-2	Fixed Gages, Dividers, Calipers and Micrometers
Module 27-3	Gage Blocks, Mechanical Comparators and Electronic Comparators
Module 27-4	Angle Measurement Instruments, Optical Projectors and Surface Texture Gages
Module 27-5	Tolerancing
Module 27-6	Calibration
Module 27-7	Statistical Techniques in Metrology
Module 27-8	The Total Measurement System

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This module was prepared for General Physics Corporation by Ben Selleck, Ben-Sel Associates, and John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Many different types of measuring devices are available for use in dimensional inspection. The primary factors involved in selection of the "best" device are the type of dimension to be measured, the tolerance of the dimension and the characteristics of the measuring device. Modules 27-2, 27-3 and 27-4, describe various types of measuring devices, their typical applications and sources of errors in measurements with each type. Module 27-5 describes tolerancing methods. Then, after discussion of calibration and sampling techniques in Module 27-6 and 27-7, the total measurement system is described in Module 27-8. Therefore, this module and the subsequent ones lay the foundation of the total measurement system is described by Module 27-8.

This module describes fixed gages, dividers, calipers, vernier and dial calipers, and micrometers. The student/trainee should give particular attention to the application and sources of error with these instruments. Also, the student/trainee should practice making measurements with these instruments to develop skill in measuring with accuracy and precision.

MODULE PREREQUISITES

The student/trainee shall have completed Module 27-1.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Given a type of divider, caliper, vernier, micrometer or fixed limit gage, name at least one typical use of the instrument.
2. Given a type of divider, caliper, vernier, micrometer or fixed limit gage, name at least three sources of error in measurements with the instrument.
3. Define a GO and NOT GO limit gage and describe the differences between master fixed gages and limit fixed gages.
4. Demonstrate the ability to interpret Unified System thread designators.
5. Demonstrate the ability to make measurements with dividers, calipers, verniers, micrometers, and fixed limit gages, and to determine sources of errors in these measurements.

NOTES TO INSTRUCTOR / STUDENT

Laboratory exercises are recommended to develop student/trainee skills in making measurements with the instruments described in this module. The module includes suggested exercises and procedures for this purpose although the instructor will need to tailor these to local circumstances. Advance preparation will be necessary to provide for a selection of parts to be measured: (Suggested parts are included in the activities and materials of this module.); the instruments to be used: (Suggestions are included in

the activities and materials of this module); standards to be used and whether the student/trainee or the instructor will apply the standard for accuracy checks.

FIXED GAGES

Fixed Gages

Fixed gages do not measure actual size but merely determine whether work pieces are within limits of tolerance. Fixed gages are classified as either master gages or limit gages. The master gage is manufactured to represent the dimension to be measured. In this capacity, the master gage serves as a standard for calibrating other instruments. The limit gage is manufactured to represent the limit of a toleranced dimension. In this role, the limit gage is an inspection device. Two limit gages are necessary. One for measuring one extreme of the tolerance and the other for measuring the other extreme. However, both measurement surfaces may be integral with one instrument.

Principles of Limit Gage Measurements

Limit gages are made to sizes essentially identical to the tolerance limits of the dimension to be inspected. The accuracy in being identical to the tolerance limits is based on standard gage makers tolerances, which classify gages by their accuracy. For example, Table 27-2-1 lists gage makers tolerances for cylindrical plug and ring gages.

Table 27-2-1 Gage Maker Tolerances for Cylindrical Plug and Ring Gages

RANGE AND TOLERANCES					
Size Range		Class XX	Class X	Class Y	Class Z
Above	To and Including				
0.29	0.825	0.00002	0.00004	0.00007	0.00010
0.825	1.510	0.00003	0.00005	0.00009	0.00012
1.510	2.510	0.00004	0.00008	0.00012	0.00016
2.510	4.510	0.00005	0.00010	0.00015	0.00020
4.510	6.510	0.000065	0.00013	0.00019	0.00025
6.510	9.010	0.00008	0.00016	0.00024	0.00032
9.010	12.010	0.00010	0.00020	0.00030	0.00040

Whenever a specific limit gage can enter an inside dimension or an outside dimension can enter the limit gage, the measured dimension will assemble with a mating part whose boundaries are equal to those of the gage. The conclusion is that the part will "go" at assembly and, hence, the designation of this limit gage as the GO gage. The GO gage is defined as a limit gage that contains the reverse physical replica of the dimension to be measured at its maximum permissible material condition. That is to say, when determining the *reverse physical replica* of the dimension to be measured, it should be realized that for determining whether a cylindrical hollow tube is of the proper inside diameter, a solid cylindrical rod could be inserted to verify that the tube dimensions are proper.

In similar manner, if a cylindrical rod outer diameter is to be verified, a hollow cylindrical tube could be used as the *reverse physical replica* for this measurement.

For outside dimensions, the GO gage equals the maximum permissible size of the dimension to be inspected. For an inside dimension, the GO gage equals the minimum permissible size of the dimension to be inspected. Under each of these circumstances, maximum material is present.

In addition to assuring assembly, the function of the assembled parts is dependent on the tightness of assembly. Therefore, the minimum material condition has limits intended to assure the proper function of the parts. If a limit gage is made to coincide with the minimum material condition, an acceptable part should not enter the gage or the gage should not enter the acceptable part. The NOT GO gage is defined

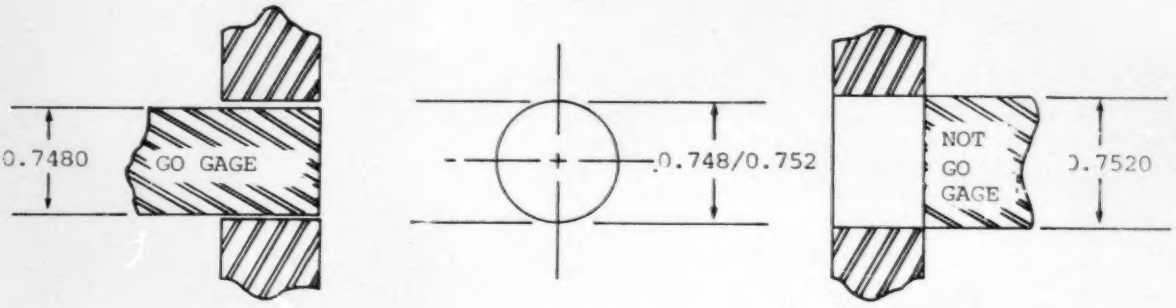


Figure 27-2-1. Product Features as measured by a GO and NOT GO gage.

as a limit gage that contains the reverse physical replica of the dimension to be measured at its minimum acceptable material condition. Thus, for outside dimensions, the NOT GO gage equals the minimum permissible size of the dimension to be inspected. For inside dimensions, the NOT GO gage equals the maximum permissible size of the dimension to be

inspected. In each case, the dimension is at the minimum material condition. The use of GO and NOT GO limit gages for an inside dimension is illustrated in Figure 27-2-1.

A typical example of a GO and NOT GO gage is shown in Figure 27-2-2. In this figure, the GO plug should enter the hole in the part and the NOT GO plug should not. However, when making measurements one should be aware of the fact that every single time any gage or measurement instrument is used it wears. Also, everytime a part is measured it wears. This wear is very minor, but it is definitely measureable, and must be taken into consideration. This particular fact is often misunderstood. For example, literally tens of thousands of very expensive class XX plug gages are purchased every year for applications where they wear into class X tolerance gages within the first few minutes of use. The moderately priced class X gages could have been bought in the first place. Wear is so important that it is recognized in the specifications of gages that have been standardized. It is called the wear allowance. Those who go into industrial measurement will become well acquainted with it. Figure 27-2-2 also shows the wear allowance on the GO plug denoting that it reduces the tolerance specified for the hole to be measured.

Limit Gage for Length Dimension

The snap gage and the limit length gage are two common limit gages for measuring outside length dimensions. These gages often contains adjustable measurement surfaces to permit setting the gage with a master within a range of GO and NOT GO limits. Rather than requiring two gages, GO and NOT GO features are normally contained by a single gage. Gage sizes range from about 1/8 of an inch to 40 inches. Figure 27-2-3 illustrates these two gages.

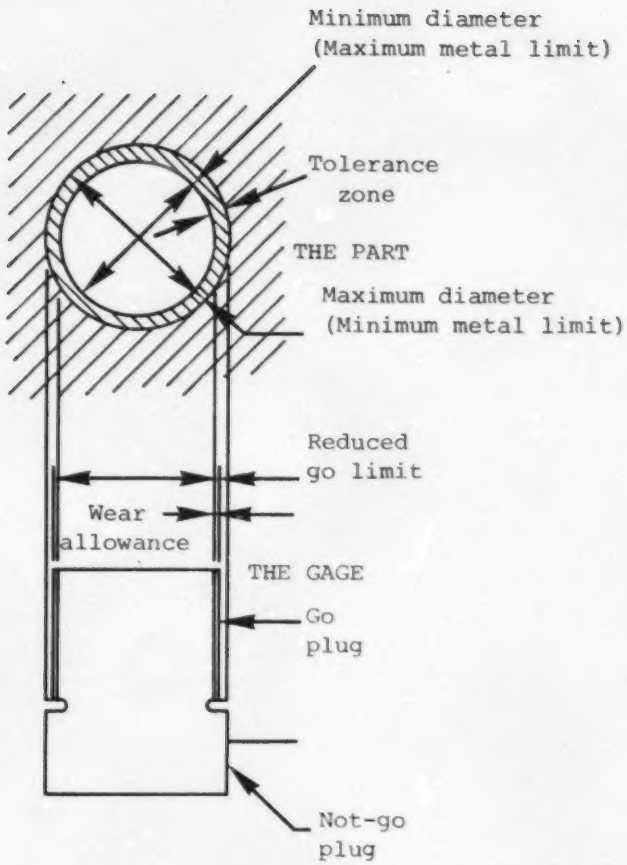
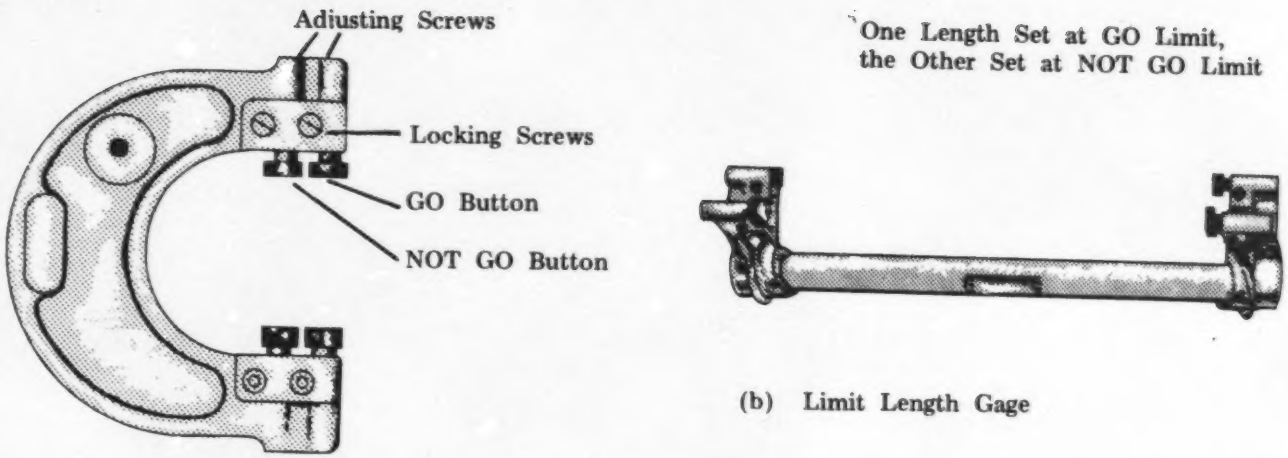


Figure 27-2-2. The GO plug should enter the hole in the in the part. The NOT GO plug should not. The wear allowance on the GO plug reduces the tolerance specified for the hole.



(a) Limit Snap Gage

(b) Limit Length Gage

Figure 27-2-3. Outside Length Limit Gages

The snap gage is a set of fixed calipers and can be used in checking most outside dimensions where a micrometer might be used. In long production runs, it has a distinct advantage over the more familiar mike, in that it does not have to be adjusted and read out each time it is used. The outer gaging button, where the workpiece enters the gage, is set at the GO dimension. That is the distance between the adjustable and the fixed anvils must be equal to - or slightly less than - the maximum dimension permitted by the part tolerance. The inner button is set to the NO GO or minimum dimension. Thus, the GO-NO GO test is quick and easy. A workpiece in tolerance will pass the outer pin and stop at the inner pin. An oversize piece will not enter and an undersize piece will pass under both pins, as shown in Figure 27-2-4.

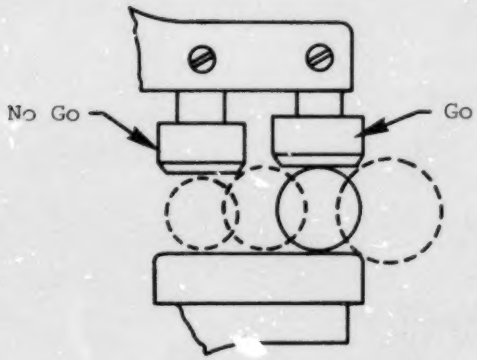


Figure 27-2-4. Use of the Snap Gage.

Limit plug gages are fixed gages for measure inside lengths between flat, parallel surfaces or inside diameter of large bores. The contact surfaces are spherical for bore measurements. Two styles of these gages are shown in Figure 27-2-5. The style in detail (a) is made in sizes from about 2 1/2 to 4 1/2 inches. The style in detail (b) is made for larger sizes up to about 12 inches.

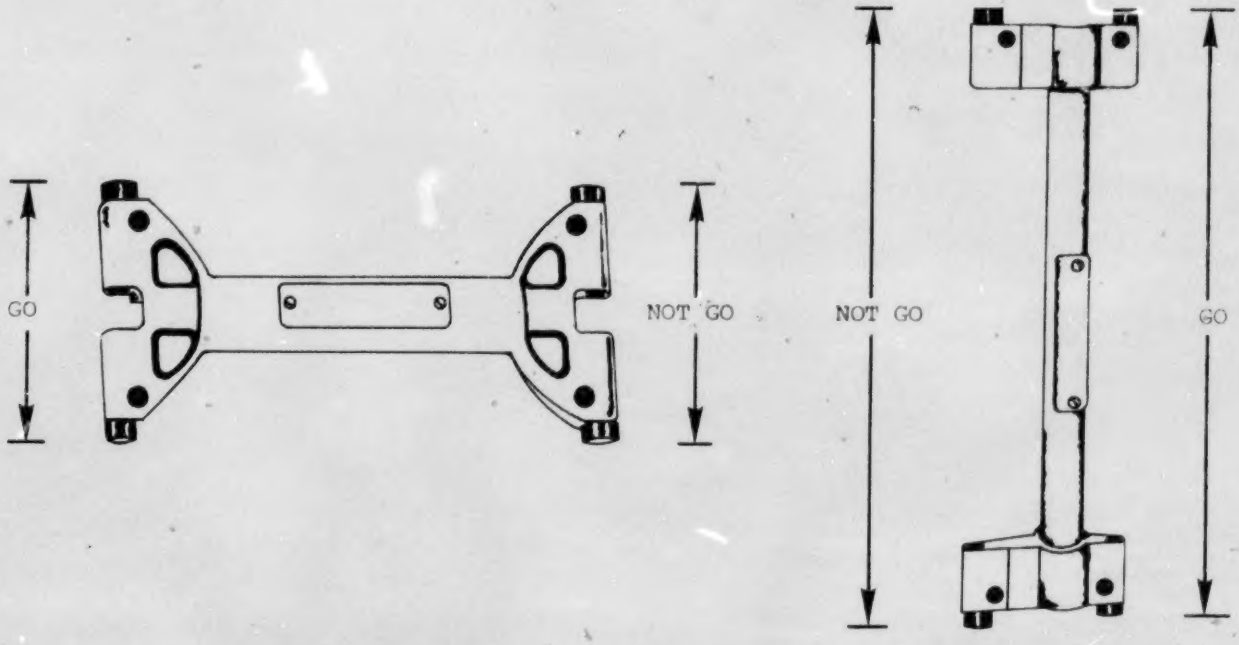
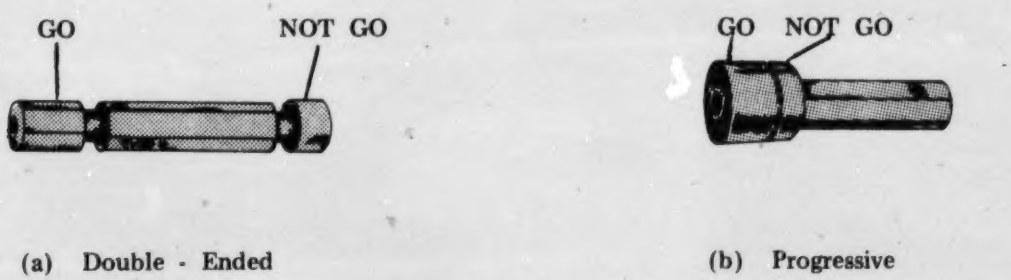


Figure 27-2-5. Inside Length Limit Gages

Cylindrical Limit Gages

Measurement of the diameter of a cylindrical part pertains to a single length dimension. But the diameter probably varies at different degrees of rotation and at different lengths (depths) of the cylinder. The effective size of the cylinder includes the form of the cylinder, i.e., its roundness and cylindricity. Cylindrical limit gages are designed to measure not only the diameter but the form of a cylindrical part.

Cylindrical Plug Gages are used for measurement of round holes. They can also be used for gaging slot widths between parallel walls. Most cylindrical plug gages have the GO and NOT GO members mounted on the same handle to permit gaging both limits with one device. Figure 27-2-6 illustrates the double ended cylindrical plug gage in detail (a) and the progression cylindrical plug gage in detail (b).



(a) Double - Ended

(b) Progressive

Figure 27-2-6 Cylindrical Plug Gages

The GO section in each is longest because an acceptable bore must accept the GO gage the full depth of the bore. Various designs of cylindrical plug gages permit measurement between about 0.030 inch to 12 inches.

Cylindrical Ring Gages

The counter-part of the cylindrical plug gage is the cylindrical ring gage. The cylindrical ring gage measures the outside form of a basically round shaft. These gages are used in lieu of snap and length gages when the effective diameter of the part is to be measured. Separate GO and NOT GO cylindrical ring gages are used for measurement. This permits moving the GO ring gage the entire length of the shaft. The two are distinguishable by a groove on the NOT GO cylindrical plug gage as shown in Figure 27-2-7. It is noted that the GO cylindrical ring gage is not a good indicator of roundness and the NOT GO measurement is made only at the end of the shaft.

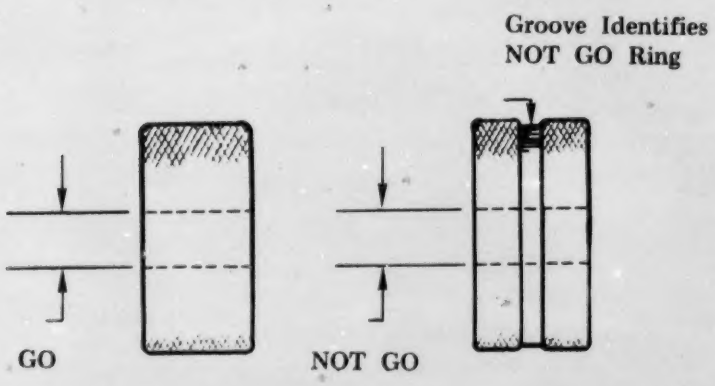


Figure 27-2-7. Cylindrical Ring Gages

It should be pointed out that the NOT GO rings and plugs do not inspect a diameter in the same sense as the GO members. When they fail to engage the part, it claimed to be in size *by agreement* between contractors. Actually it

is possible, for example, that a shaft may be larger on the ends than it is in the middle. Or it may be slightly out-of-round. These conditions would not be detected. As the need for precision increases, the NOT GO check becomes less satisfactory and the results should be spot-checked by some other means, such as a micrometer or a snap gage. Some quality control departments order their NOT GO plugs flatted and their rings relieved as shown in figure 27-2-8, so that the diameter is checked in small segments. An out-of-round condition can often be detected by rotating such a gage.

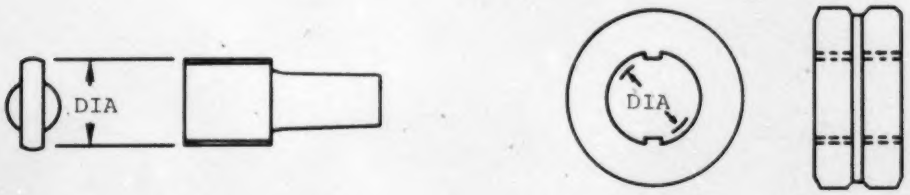


Figure 27-2-8. Modified NOT GO Gages for checking out of round conditions.

Fixed Gages for Multiple Dimensions

There are certain standardized parts having forms consisting of several dimensions that establishes their actual size. A threaded fastener is a good example of such a part where the major, minor and pitch diameters, threads per inch, lead angle, and thread form all affect the effective size. Envelopes of acceptable sizes of such parts can be calculated based on the cummulative effect of tolerance of individual dimensions. Fixed gages are sometimes used to measure such an envelope of tolerances.

Thread limit gages are comprised of thread plug gages for measurement of thread holes and thread ring gages for measurement of threaded shafts. Design of these gages is based on standardized thread designs of the Unified System illustrated in Figure 27-2-9.

Thread limit plug and ring gages are available in the same range of sizes as the cylindrical plug and ring gages. As illustrated in Figure 27-1-10, thread plug gages are fixed and thread ring gages can be of an adjustable design. The adjustable thread ring gage is set with a master thread plug gage of the desired thread form. GO thread gages check the maximum material size. HI and LO thread gages check the minimum material size. In use, the GO gage must engage the thread for its entire length while the HI or LO gage must result in a definite drag on or before engagement of the third thread. (Gages should never be forced.)

Roll thread snap gages provide a faster method of inspecting external threads that is offered by thread limit ring gages. The gage jaws of the roll thread snap gage are pairs of free-turning rolls comprised of annular rings, i.e., they are not cut in a helix like a screw thread. The GO rolls have full thread profile for checking the maximum material condition of threads. The NOT GO rolls are truncated and check the pitch diameter at minimum material condition.

Tapered threads are checked with a roll-type set at the desired taper. Tapered roll thread gages are available for checking both internal and external threads. For acceptance of external tapered threads, the gage must thread onto the part until the face of the gage is flushed with the end of the threaded portion of the work piece as shown in Figure 27-2-11. Falling short or exceeding the flush condition results in the rejection of the tapered external thread.

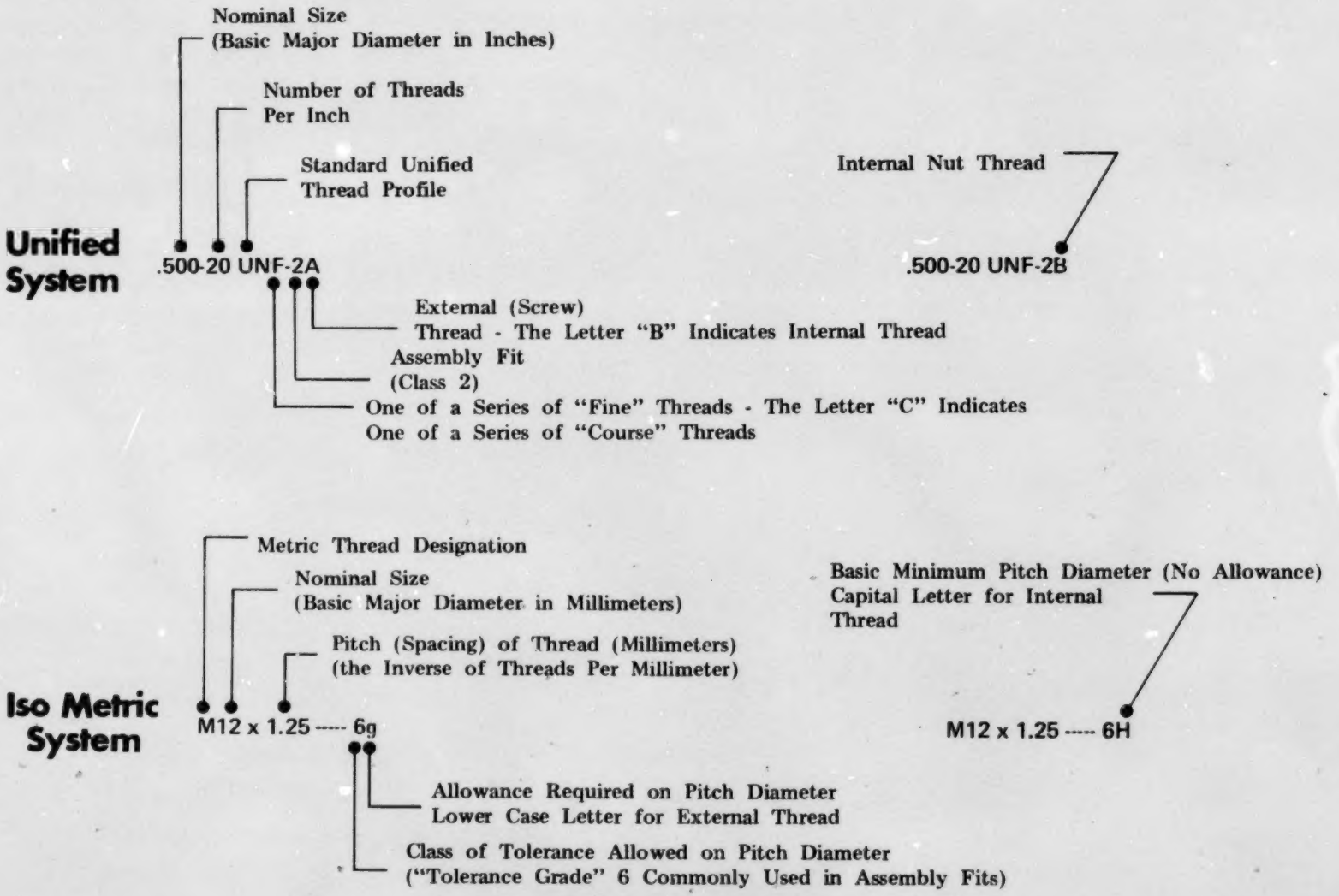


Figure 27-2-9. Thread Designation Systems

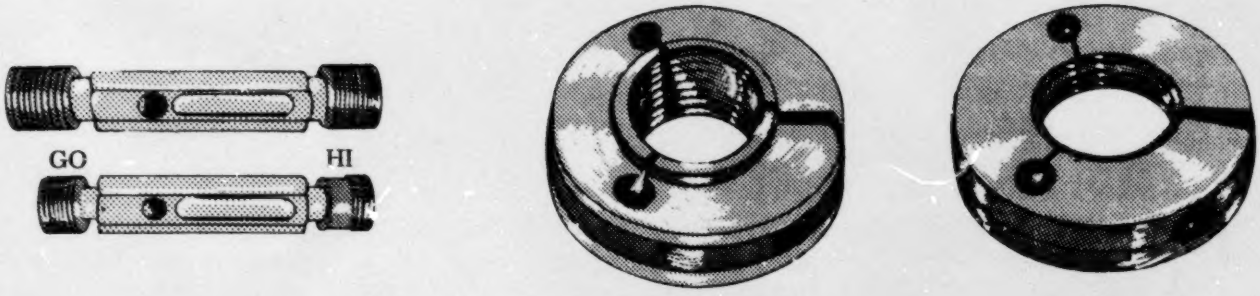
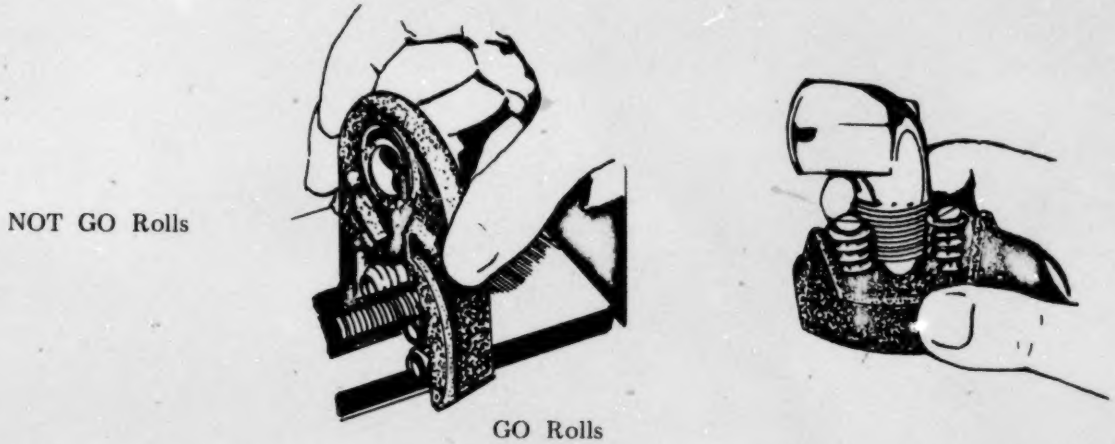


Figure 27-2-10 Thread, Plug and Ring Gages



a. Roll Thread Snap Gauge

b. Tapered Roll Thread Gauge

Figure 27-2-11 Roll Thread Gauges

For internal tapered threads, the gage has a flat or scribe mark which denotes the position to which the gage should enter the tapered, tapped hole. Entry of the gage short of or beyond the flat or mark results in rejection of the part.

Taper plug and ring gages are used for measurement of tapered bores and shafts respectively. The taper is normally of concern from a reference diameter. Therefore, the taper plug and ring gages are scribed or grooved at the reference diameter. Since tapers are used for snug or press fits at assembly, the taper plug or ring gage should not wobble when placed to the reference diameter. Prussian blue may also be used. If the bluing is uniform over the workpiece or instrument, the tape is acceptable, Figure 27-2-12 pictures taper plug and ring gages.

Taper Plug

Taper Ring

Figure 27-2-12. Taper, Plug and Ring Gages

Accuracy and Precision of Fixed Gages

The manufacturing tolerances and stability of materials have the largest effect on the inherent accuracy of fixed gages. Wear of mating surfaces during use of these gages will deteriorate accuracy as was discussed previously regarding GO and NOT GO gages.

The most important inspector's techniques pertain to cleanliness of the gage and workpiece and "feel" of the gage. Small amounts of dirt or other foreign material can cause erroneous rejection of good parts or acceptance of bad parts.

The "feel" of the gage includes proper positioning (similar to positioning the micrometer) and pressure applied to the GO and NOT GO members. In general, fixed limit gages should "go" or "not go" with finger pressure. If the muscles of the arm are being used to force the gage, too much pressure is being applied.

The accuracy and precision of measurement with the fixed limit gage is primarily dependent on the inspector's feel. For this reason, and because quantitative data is not generated for process control, fixed limit gages used in the inspection of items for nuclear power plants is mostly limited to cylindrical plug and ring gages and thread plug and ring gages. Taper and spline plug and ring gages see some use.

CALIPERS AND DIVIDERS

Description

Calipers and dividers are types of transfer devices that require supplementary gaging or modified design to give a readout. Basic types of calipers and dividers are shown in Figure 26-2-13.

All of the devices shown in Figure 27-2-13 are purely transfer devices, i.e., they do not contain a self contained readout. More sophisticated designs of these instruments add a line-graduated scale that permits direct readout. The most common of these with direct readout is the slide caliper. It is not difficult to envision a scale along the beam of the slide caliper in Figure 27-2-13 that would give a direct readout. Since such direct reading slide calipers are normally also equipped with a second scale (vernier), they are discussed later in this module.

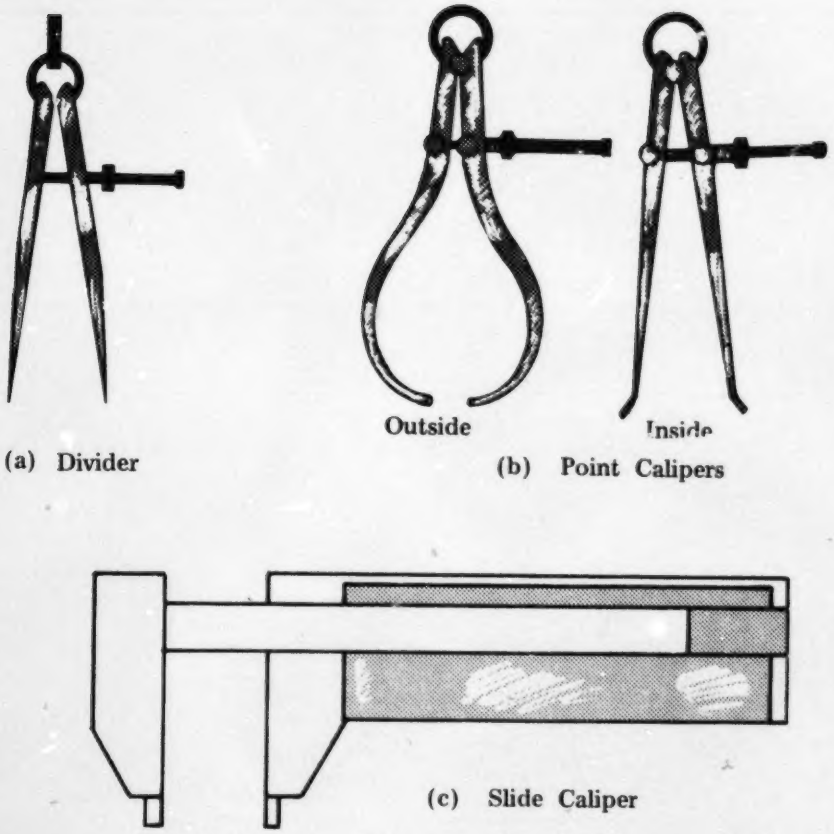


Figure 27-2-13 Divider, Pointer Calipers, Slide Calipers

Application

Dividers and calipers are used for measurement where accuracy and precision requirements are equal to that of the steel rule. These devices essentially eliminate the major source of error of the rule, i.e., alignment of the length boundaries with the graduations of the rule.

The divider provides for point measurement. One tip is placed at a point of one boundary and the span of the divider is adjusted such that the other tip is at the point of the other boundary. The thumb nuts permit clamping of the dividers at the span setting. Common uses of the

divider include scribing circles and arcs, establishing center points for center punching, and measuring distances between reference points or lines. Figure 27-2-14 shows dividers being used to find the center of a steel shaft.

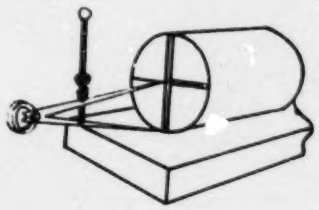


Figure 27-2-14 Dividers being used to find center of shaft. (South Bend Lathe)

The outside caliper is used primarily for measuring outside diameters of cylindrical parts (solid or hollow) as shown in Figure 27-2-15.

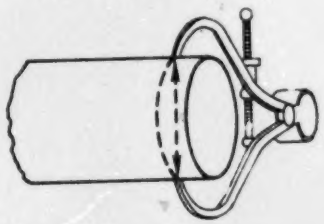


Figure 27-2-15 Measuring diameter of shaft, using an outside caliper. (South Bend Lathe)

The inside caliper is used primarily for measuring inside diameters of bored or drilled holes or hollow cylindrical parts as shown in Figure 27-2-16.

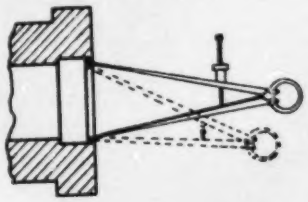


Figure 27-2-16 Using inside caliper to measure diameter of counterbore.

Again, the thumb nuts permit clamping of the calipers at the span setting.

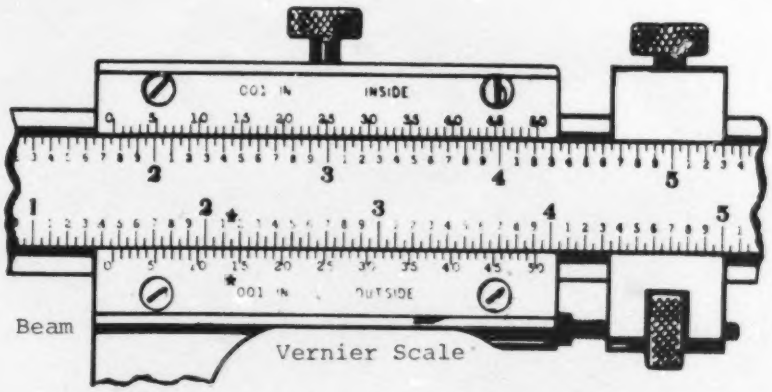
The slide caliper is used for measuring lengths and diameters where the tips of the jaws can be fitted against the boundaries. Jaws of most slide calipers permit both inside and outside fitting against the measurement boundaries.

VERNIER AND DIAL CALIPERS

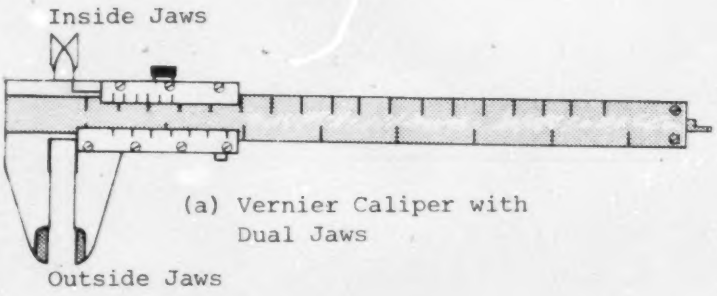
Description of Vernier Calipers

Vernier calipers are designed around the principle of a graduated bar with a stationary jaw and a movable jaw. The primary scale is scribed on the beam of the stationary jaw. To the movable jaw, a vernier scale added. The caliper is normally equipped with a fine-adjustment feature that permits a more uniform "feel" of pressure on the tips of the jaws. On standard vernier calipers, both inside and outside readings are taken from the same set of jaws. On others, two sets of jaws are provided. Verniers are

available with both inch and centimeter units. Vernier plates are available with either a 25- or 50- division scale. Figure 27-2-17 pictures a vernier caliper with separate sets of jaws for inside and outside measurements. It also shows a close-up of a 50 division vernier scale. In the close-up view, the fine adjust and set screws are clearly visible.



(b) Vernier Scale



(a) Vernier Caliper with Dual Jaws

Figure 27-2-17 Vernier Caliper

Reading the Vernier Caliper

Reading the vernier caliper is explained based on the vernier scale shown in Figure 27-2-17(b). The upper scale is used in conjunction with measurements with the inner jaws. The lower scale is for measurements with the outer jaws. The lower scale is explained; reading the upper scale is similar.

The basic reading on the beam is at the zero point of the vernier. When this zero does not coincide with a division on the beam, the graduation value on the beam immediately preceding the vernier zero is supplemented by a value obtained from the vernier. The supplementary value is the value of the vernier that exactly aligns with any of the graduations on the beam. Thus, the total value of the vernier is equal to the value of one graduation on the beam. The principles used in reading the vernier scale will apply to any vernier instrument. Ted Busch[1] outlines a technique for reading a vernier scale. The discussion which follows discloses the essence of his technique.

Consider a vernier scale measuring length in inches. The main scale is divided into inches. Each inch is divided into inches. Each inch is divided into ten parts, and each of these divisions is subdivided into quarters, as shown in Figure 27-2-18. The smallest divisions are thus 1/40 in. One thousand divided by 40 is 25; therefore the smallest divisions are 0.025 in. and read as units of 25 *mil*. Note that from its start, the vernier has been a decimal instrument, not fractional.

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[1] Ted Busch, Fundamentals of Dimensional Metrology, Delmar Publishers

READING A VERNIER IN INCHES

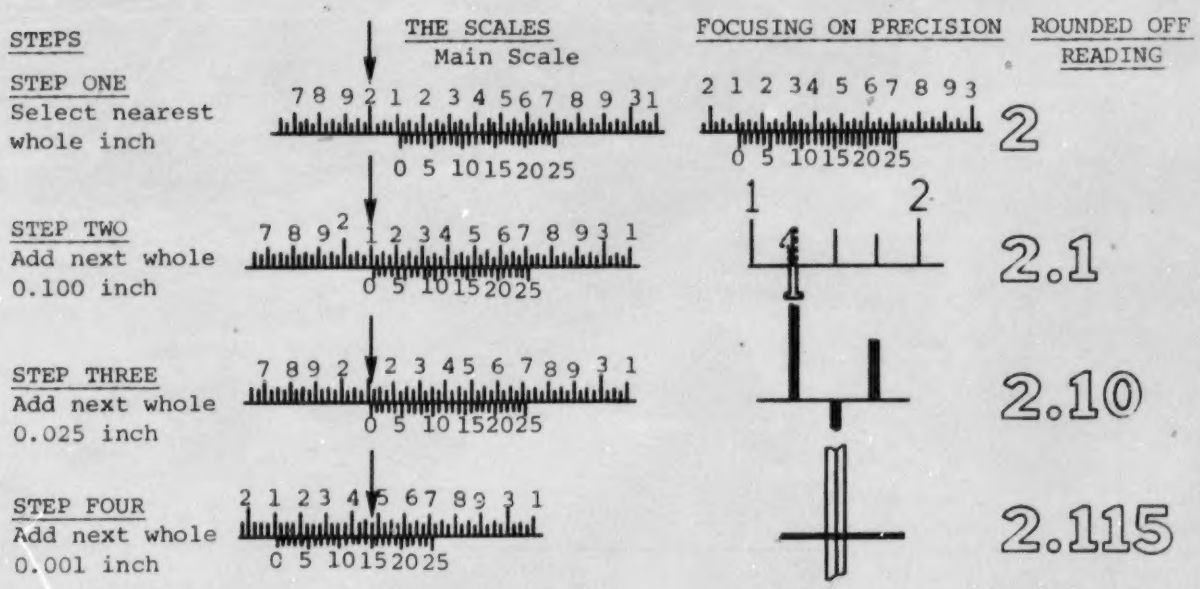
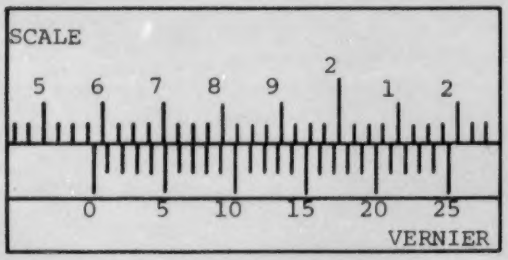


Figure 27-2-18 Reading a Vernier in Inches

Each of the steps for reading a vernier raises the results to a higher level of precision, much like focusing a microscope.

In a caliper the vernier scale is attached to the sliding jaw and moves along the main scale. It has 25 divisions in the same length that the main scale has 24. The difference between a main scale division and a vernier division is 1/25 of a main scale division. Hence, 1/25 of 0.025 in. is 0.001 in. or *one mil*. This is the discrimination of the instrument, and is called the *least count*. A vernier is read by adding the total readings from the main scale to the thousandths readings on the vernier scale. This applies to the controls on machines as well as scales on instruments, as shown in Figures 27-2-18 and 27-2-19.



FROM A VERNIER CALIPER 1.582

Figure 27-2-19 Practice is required for reliable reading of vernier scales.

The steps in reading a venier caliper are as follows:

1. Read the number of whole inches on the main scale that appear to the left of 0 on the venier.
2. Read the highest numbered graduation on the main scale that lies to the right of the index (0) on the vernier scale. Read these graduations as even one hundred *mil* (0.100, 0.200, etc.). Add to the whole inches from step one (1.100, 2.100, etc.).
3. Read the highest number of whole minor divisions to the right of the index. Read these graduations as even twenty-five *mil* (0.000, 0.025, 0.050, and 0.075 in.). Add to the sum of steps one and two (1.125, 1.150 in., etc.).
4. Now find the vernier graduation that most perfectly coincides with *any* graduation on the main scale. That is the nearest *mil* and may be any whole number from zero to 25 (0.000, 0.001, ... 0.024, 0.025). Add this to the sum of the previous three steps. It should be noted that only when the vernier is at zero will two lines, 0 and 25, for the vernier scale coincide with the main scale.

The principle is the same for metric verniers, as shown in Figure 27-2-20. Some modern instruments have both inch and metric scales. These provide the best of both worlds.

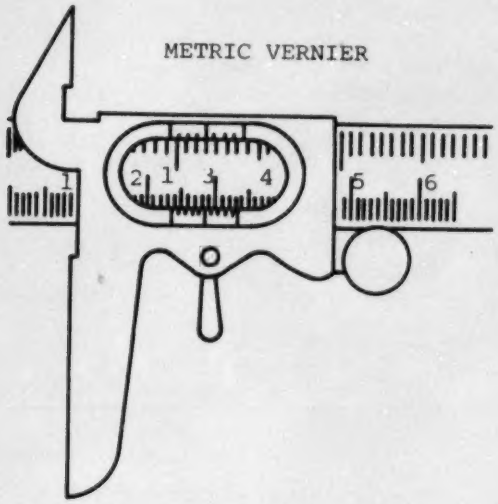


Figure 27-2-20 Nearly all vernier instruments are available with metric scales.

The advantages and disadvantages for vernier instruments are summarized in Table 27-2-2. Here is the essential point. Vernier scales are usually more reliable than the instruments on which they are used. It might be asked why the discrimination is limited? Could not the entire arrangement be expanded so that the discrimination to be reduced to, say, 0.0001 instead of 0.001 in.? A vernier designed to read to 0.0001 from an inch scale would have a group of lines so nearly in coincidence that they would be indistinguishable. Many modern vernier instruments do have expanded scales. The objective, however, is to achieve greater reliability by improved readability.

Table 27-2-2

ADVANTAGES AND DISADVANTAGES OF VERNIER SCALES

Advantages:

1. Amplification is achieved by design and is not dependent upon moving parts that may wear or go out of calibration.
2. No interpolation is possible in reading, let alone required.
3. There is no theoretical limit to the scale range (length).
4. Zero setting adjustment is easy.

Disadvantages:

1. The principal disadvantage lies in the instruments on which verniers are used.
2. The reliability of reading depends more upon the observer than most instruments.
3. The discrimination is limited.
4. No way to adjust for any errors other than zero setting.

An example of the vernier scale was shown in Figure 27-2-17(b). This modern 50-division vernier makes use of the amazing ability of the eye to bring lines into coincidence. It requires twice the visual acuity of a 25-division vernier, but is quite easy to use. Note that it does not increase the accuracy (that is mostly in the instrument construction), or the discrimination, but does increase the reliability.

In Figure 27-2-17(b) the beam graduations are shown to be in increments of 0.05 inch. The vernier has 50 graduations, each of which is equal to 0.05 ÷ 50 or 0.001 inch. Reading the vernier caliper of Figure 27-2-17(b) gives the following results:

Reading of Vernier Zero on Beam =	1.45 plus inches
Matching Graduation of Vernier with Beam =	.014 inch
Composite Reading =	1.464 inches

Figure 27-2-21 shows this reading.

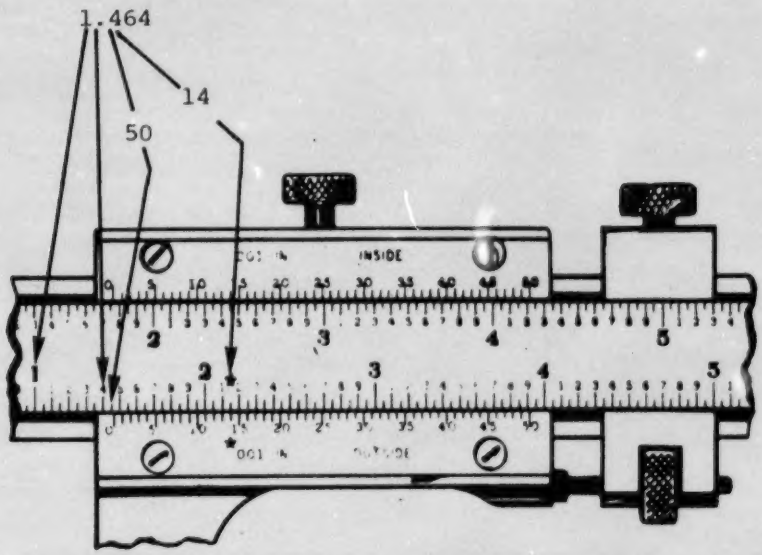


Figure 27-2-21 Reading a Vernier-50 Division

Description of Dial Caliper

Dial calipers are very similar to vernier calipers except that the vernier is replaced with a dial indicator. One revolution of the dial indicator is the equivalent of the vernier scale. Therefore, the reading of the dial indicator is added to the reading of the beam as shown in Figure 27-2-22.

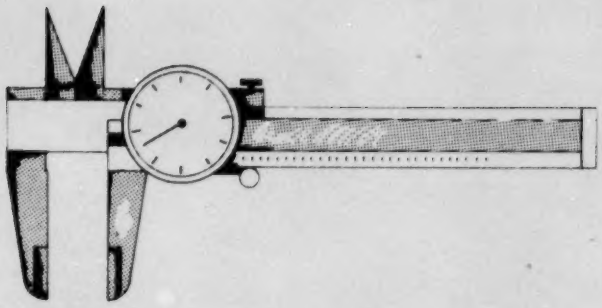


Figure 27-2-22 Dial Caliper

Applications of Vernier and Dial Calipers

Vernier and dial calipers are general purpose length measurement devices. Their sensitivity is 0.001 inch. Dial calipers give best accuracy of about 0.001 inch per 6 inch length of measurement. These devices provide for relatively fast measurements of lengths, diameters, widths, and heights. They are suitable devices for any of these features having a tolerance of 0.004 inch or more.

Sources of Error of Vernier and Dial Calipers

The manufacturing tolerances of the instruments establish the maximum possible accuracy and precision. Manufacturing tolerances are most critical for the width and surface finish of the contact portion of the jaws, the parallelism of the faces of the jaws, the perpendicularity of the faces of the jaws to the beam, the scale linearity, width of graduation lines, and the intervals of the dial indicator. Super smoother, knife edges of the jaws provide esentially a point contact with the boundaries of the dimension to be measured. This is particularly important when such boundaries have a radius. The dial indicator adds a new source of error referred to as hysteresis.

Hysteresis refers to a lagging of movement when direction of motion is changed. It affects both accuracy and precision.

Other sources of error are operator and procedure oriented. Positional consistencies and full and accurate reading of scale are important to operator techniques and precision. Standardization of calibration within a laboratory and from one organization to another is important.

MICROMETER

Description

Micrometers are specially designed calipers that work on the principle of a screw with a precisely controlled lead. A given rotation of the screw moves the spindle (movable jaw) a predictable distance such that accurate measurement is possible. The principal parts of a micrometer are shown in Figure 27-2-23.

The C-shaped frame should be used as the "handle" of this device. The spindle, thimble, and thimble sleeve are integrally connected to the lead screw (not visible in Figure 27-2-23). Turning the thimble sleeve turns the lead screw such that the span between the spindle and anvil becomes smaller or larger dependent on direction of rotation. The primary scale is on the barrel sleeve and is graduated in increments of 0.025 inch. The secondary scale is on the thimble, and is graduated in 25 increments with each increment equivalent to 0.001 inch movement along the sleeve scale. Some micrometers also have a vernier such as that shown in Figure 27-2-23. The vernier has ten graduations with each representing 0.0001 inch. The spindle lock serves to hold the spindle at the desired span when "locked". The friction nut is a ratchet device that helps

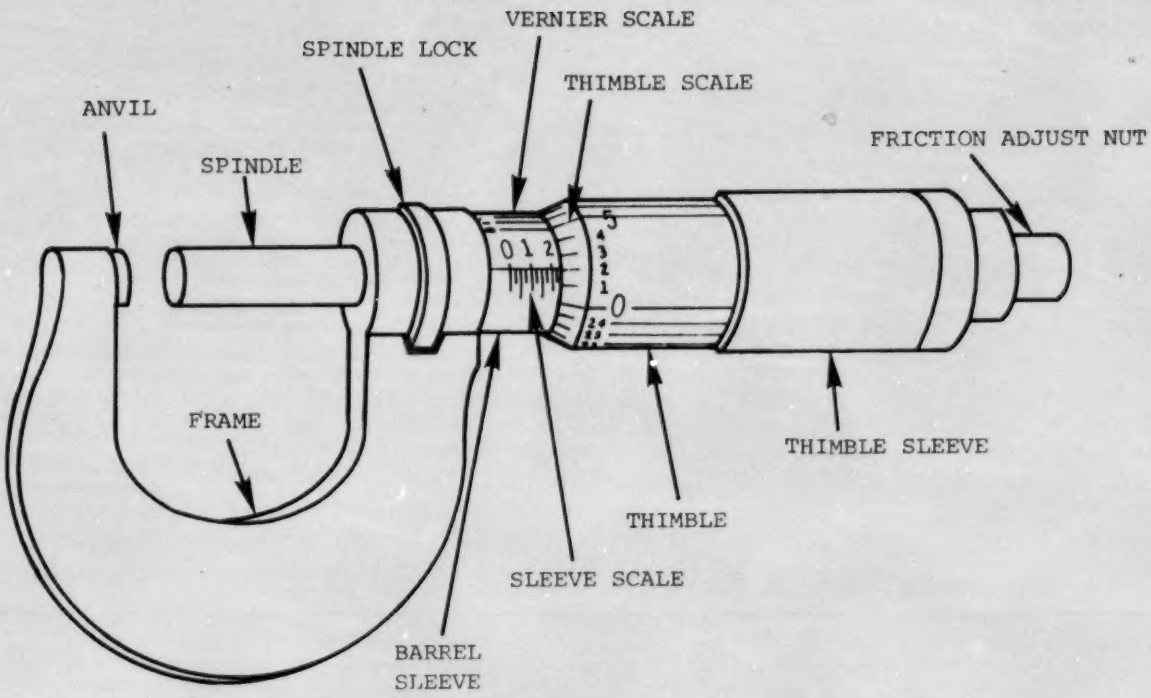


Figure 27-2-23 Micrometer Nomenclature

to insure uniform pressure against the boundaries when measurements are made.

Micrometers are made in many sizes with either inch or millimeter units. They are designated by the maximum size that can be spanned by the frame. However, the spindle travel is normally only one inch for any size. For example, while a one inch micrometer measures from 0" to 1", a 2" micrometer spans two inches but still has one inch of spindle travel. Thus, the 2" micrometer measures from 1" to 2". Sets of micrometers are available in one inch increments up to a span of 18" with each having the usual one inch of spindle travel. Metric micrometers have equivalent ranges with the smallest from 0mm to 25mm and with larger spans up to 600mm. On larger micrometers,

interchangeable anvil extensions are utilized to reduce the span in several increments for the sake of economy.

Micrometers have such improvements and special features as friction sleeves, ratches stops, spindle locks and slant line graduations as well as vernier scales that read to one/ten-thousandths (0.0001") of an inch. Probably the most dramatic mechanical change to occur in recent micrometer design is the advent of the direct reading digital micrometer. Digital micrometers can display a digital readout to 0.0001" in the U.S. System and 0.002mm in the S.I. System. The readout occurs in a non-revolving window built into the thimble of the micrometer.

Reading the Micrometer

The operation of a micrometer is based on an accurately machined screw, usually having 40 threads to the inch. With one complete revolution, such a screw will advance 1/40th or 0.025 of an inch. By putting graduations on the barrel sleeve which is fixed and on the thimble which moves with the screw, it is possible to determine the amount of movement of the screw, and thus to measure.

On inch reading micrometers, 40 graduations are placed on the barrel to match the number of threads on the screw such that each represent 0.025 inch of movement. To facilitate reading, every fourth line is numbered to show 0.100", 0.200" etc. to 1". (These correspond to the 0, 1 and 2 visible on the sleeve scale of Figure 27-2-23.)

The beveled edge of the thimble has 25 divisions around the circumference, numbered from 0 to 25. A beveled edge is used to reduce the parallax with the sleeve scale. When the micrometer is closed, only the zero line on the barrel can be seen next the beveled edge of the thimble, and the zero line on the thimble is aligned with the long axial line on the barrel, called the datum.

Every complete revolution of the thimble from 0° to 360° advances (or retracts) the spindle 1/40" ro 0.025" and moves the edge of the thimble from one graduation on the barrel to the next barrel graduation. With one graduation on the beveled edge of the thimble aligned with the datum on the barrel, rotation of the thimble to align the next thimble graduation with the datum moves the spindle a distance of 1/25th of 0.025" or 0.001". Because the thimble divisions, which represent 0.001" of movement of the screw, are widely spaced around the circumference of the thimble, 0.001" movement of the screw are easily seen and thus good readability is obtained.

To further increase the micrometer's capability to measure in even smaller increments than 0.001", many micrometers are made with a vernier scale on the barrel to divide thimble graduations of 0.001" into 10 parts, or 0.0001". The principle of the vernier, where 10 graduations on the barrel equal 9 graduations on the thimble, is identical with the principle employed in vernier calipers. When the thimble graduation does not lie exactly on the datum, the value of the vernier line that coincides with any graduation on the thimble is added to the reading. Thus, the reading of the micrometer in Figure 27-2-23 is 0.227 inch plus the value of the vernier which is not readable in the figure.

Metric reading micrometers are identical in principle. The differences are in the pitch of the screw, usually 50 threads per 25mm, and in barrel and thimble graduations to show 0.5mm for each revolution and 0.01 mm per thimble division. Vernier models discriminate to 0.002mm.

Types of Micrometers and Their Applications

- Outside Micrometers - The most common micrometer is the outside micrometer shown in Figure 27-2-23. It is used for measuring length dimensions where the spindle and anvil can be placed against the boundaries of the dimension. Most accurate measurement occurs when the two boundaries are parallel, flat surfaces. This permits the flats of the spindle and anvil to fit accuratley against the boundaries.
- Inside Micrometers - Inside micrometers are used for precision measurements of the diameters of holes and width of slots. With the use of supplementary measuring rods and spacing collars, holes from 1" to 12" diameters may be measured. This instrument is essentially the spindle and sleeve of a conventional micrometer and measuring rods of various lengths and diameters as shown in Figure 27-2-24. Various rod lengths permit measuring the the diameter of a hole at various depths.
- Disk or Lip Micrometer - This instrument is a conventional micrometer modified with disk-shaped anvil and spindle end. The extended "lips" of the spindle and anvil permit measurement of fin-like projections and other outside features where use of standard micrometer is obstructed as shown in Figure 27-2-25.
- Blade Micrometer - This modification of the conventional micrometer caliper has screw-driver shaped anvil and spindle end for measurements at the base of recesses, grooves, and other shallow depths of the outside dimension. The spindle is non-rotating as shown in Figure 27-2-26.

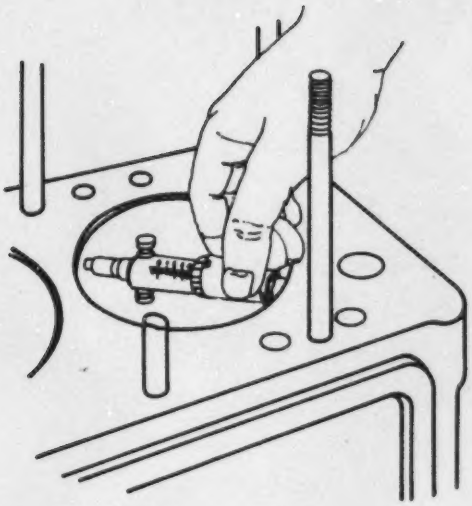


Figure 27-2-24 Using an inside micrometer to check cylinder bore size. (Austin-Healey)

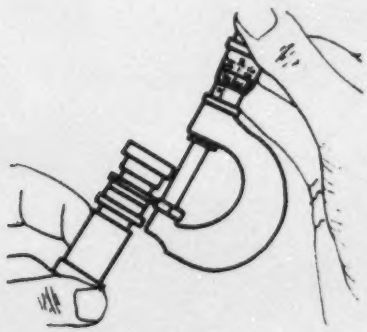


Figure 27-2-25 The Disc or Lip Micrometer

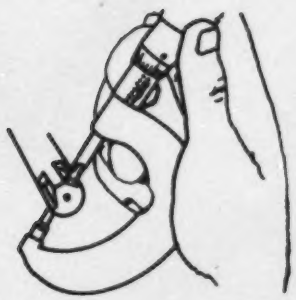


Figure 27-2-26 The Blade Micrometer

- Micrometer Depth Gage - In this instrument, interchangeable measuring rods of various lengths replace the conventional spindle and there is no anvil. The rod projects through an accurately finished base which provides a reference surface at right angles to the spindle. The rod travels as the thimble is turned, and depths up to 9" can be accurately measured as shown in Figure 27-2-27.
- Bore Measuring Micrometer (Intrimik) - This instrument permits direct measurement of hole size on a micrometer scale. It has three contact points traveling at right angles to the barrel, spaced 120° apart, which makes contact with the wall of the hole. With extension rods, readings accurate within a few ten-thousandths can be taken in holes up to 15" deep.
- Screw Thread Micrometer - This instrument is used for direct readings of the pitch diameters of screw threads. The vee-formed anvil and conical spindle tip are shaped to conform to the standard shape of the threads to be measured as shown in Figure 27-2-28.

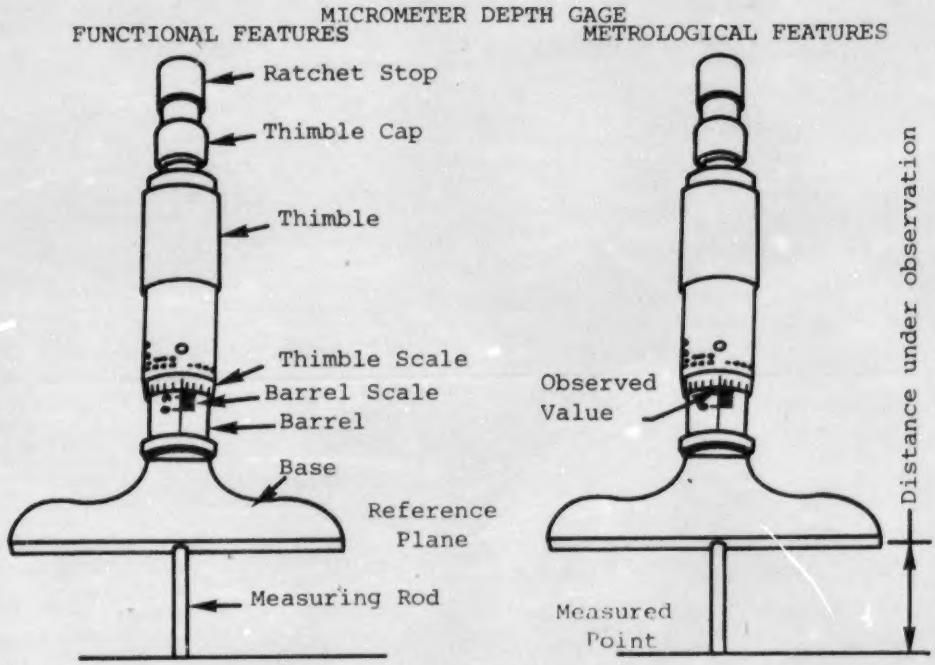


Figure 27-2-27 The depth micrometer, unlike all other micrometers, measures from a plane to a point.

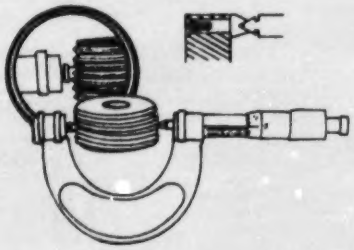


Figure 27-2-28 The Screw Thread Micrometer

- Pointed Contact Micrometer - This instrument uses conical anvil and spindle tips to measure recesses where flat tips could not reach.
- Bench Micrometer - Since the thimble graduations on a micrometer represent divisions of the smallest increment on the barrel, it is evident that enlargement of the circumference of the thimble will provide for wider spacing of the graduations and for additional finer divisions. A large thimble would be impractical on an instrument for hand use, but it is provided in the bench micrometer, which permits direct reading in 0.0001" and 0.002mm. The micrometer head is mounted on a rigid base, leaving both hands free for manipulation. Bench micrometers (sometimes called super mics) are used for outside dimensions where greater accuracy and precision are required.

Accuracy and Precision of Micrometers

Accuracy and precision of micrometers are generally better than the vernier caliper. Even with precise manufacture of these two types of instruments, the readability of the micrometer is better and the vernier of the micrometer increases sensitivity by a factor of 10.

Features of the micrometer that affect its accuracy and precision include the following:

- Spindle Thread Movement - The accuracy, linearity and stability of the thread directly affect accuracy and precision of measurements. The threads are precision ground during manufacture and hardened material is used that has good thermal stability. Wear of the threads during the life of the micrometer gradually reduces accuracy and precision. Wear

in localized areas can also be considered as altering linearity.

- Flatness and Parallelism of Measuring Surfaces - Manufacturer of the micrometer holds very tight tolerances on flatness and parallelism of the measuring surfaces. Wear of these surfaces during use will degrade accuracy and precision.
- Deflection of the Frame - Deflection of the frame during measurements reduces accuracy and precision. Such deflection is eliminated by design of rigid frames and controlling the pressure applied across the measuring surfaces. Control of measuring pressure can be improved by use of ratchets or friction sleeves on the spindle movement.
- Use by the Operator - Inadequate alignment and reading errors are the most common operator induced errors. Reading errors are reduced by practice and more practice and by attentiveness during measurement. Alignment means finding the correct span. For small outside micrometers, the best "feel" is normally by manipulation of the micrometer with one hand as shown in Figure 27-2-29. For large outside micrometers, the weight of the micrometer is supported by one hand on the frame while the spindle is adjusted with the other hand. For inside dimensions, the maximum span is sought. This occurs when the measuring surfaces are at right angles to the face of the bore. For either outside or inside measurements, the operator should select the type of micrometer that best measures the feature (See previous discussion on types of mircometers and their applications).

1. Adjust span to slightly larger than dimension to be measured.
2. Hold the micrometer with the little and ring fingers around the frame.

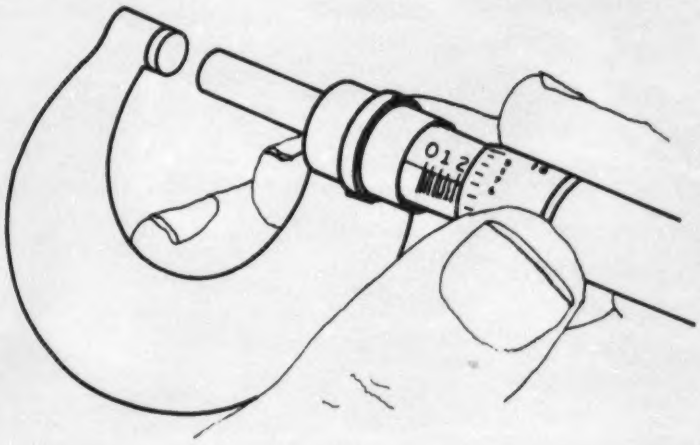


Figure 27-2-29 Manipulation of Small Micrometer

3. Place micrometer span across feature to be measured.
4. Close span by turning the thimble and forefinger.

Reading the Micrometer

Micrometers are made so that every turn of the thimble will move the spindle .025 in. You will notice that the sleeve is marked with a series of lines. Each of these lines represents .025. Every fourth one of these .025 markings is marked 1, 2, 3, 4, 5, 6, 7, 8, 9. These numbers on the sleeve indicate .001, .200, .300, etc., (one hundred thousandths etc.) markings. They will read from .000 to 1.000.

The tapered end of the thimble has twenty-five lines marked around it. They read 0, 5, 10, 15 and 20. In that

one turn of the thimble moves the thimble edge exactly .025, or one mark on the sleeve, the distance between marks is determined by reading the thimble line that is even with the long line drawn the length of the sleeve markings.

Look at the markings on the micrometer in Figure 27-2-30 there are three numbers visible on the sleeve? The 3 indicates that the mike is open at least .300 (three hundred thousandths). The thimble edge is actually past the 3 but not to the 4. By a careful study you will see that the thimble edge has moved exactly two additional marks past the 3. This means that the edge is lined up two marks past the 3. As each mark represents .025, it is obvious that the edge is actually stopped at .300 plus .050 or .350 (three hundred and fifty thousandths of an inch). In that the thimble edge 0 marking is in line with the line through the sleeve markings, the micrometer is set exactly on .350. The reading then, if this were a one inch mike (reads from 0-1 inch), would be .350.

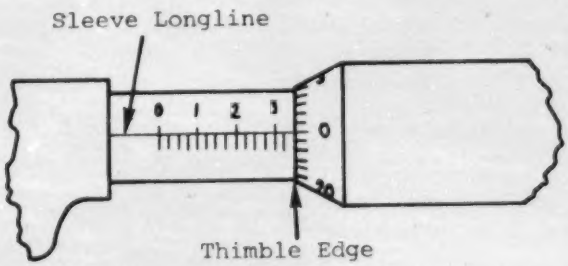


Figure 27-2-30 Micrometer reads - 0.350

In Figure 27-2-31, the micrometer has been opened to a wider measurement. You will see that the thimble edge is no longer exactly on a sleeve marking but is somewhere in between.

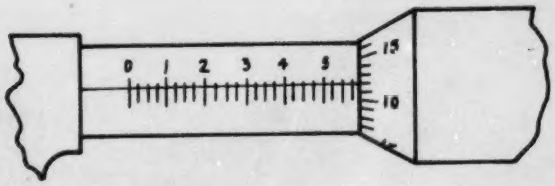


Figure 27-2-31 Micrometer reads - 0.587

How many numbers are visible on the sleeve? There are 5 or .500 (five hundred thousandths). The thimble edge has moved three marks or .075 past the .500 mark. This makes a total of .575. The thimble edge has moved past the third mark. In that the fourth mark is not visible, we know that it is somewhere between the third and fourth mark.

By examining the thimble edge marks, one will see that the twelfth mark is aligned with the sleeve long line. This means that the thimble edge has moved twelve spindle marks past the third sleeve mark. In that each thimble mark is worth .001 (one thousandth of an inch), the thimble has actually moved .012 (twelve thousandths of an inch) past the third sleeve mark. Your reading then would be .500 (largest sleeve number visible) PLUS .075 (three sleeve marks past sleeve number) PLUS .012 (twelve thimble marks past the third sleeve mark), making a total reading of 0.587 (five hundred and eighty-seven thousandths of an inch).

Study the readings shown in Figure 27-2-32. Compare your answers with those shown. Make your reading in FOUR steps.

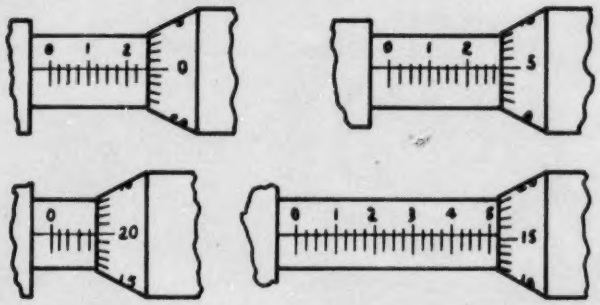


Figure 27-2-32 Reading the "mike". A-0.250. B-0.280. C-0.120. D-0.515-1/2, or 0.5155.

1. Read the largest sleeve number that is visible - each one is worth .100.
2. Count the number of full sleeve marks past this number. Each one is worth .025.
3. Count the number of thimble marks past this last sleeve number. Each one is worth .001. If the thimble marks are not quite in line with the sleeve line, estimate the fraction of a mark.
4. Add the readings in steps 1,2 and 3. The total is the correct micrometer reading.

EXERCISES

Perform the following exercises employing the procedures which are outlined in a following section in this module.

1. Measure an unknown length with a divider.
2. Transfer a standard length to a workpiece with a divider.
3. Perform a GO-NO GO measurement with a outside calipers.
4. Perform a measurement using an inside caliper.
5. Discuss the factors affecting accuracy and precision of dividers and calipers in relationship to the procedures used in making measurements with these instruments.
6. Perform the practice exercises given in the Procedures section of this module.
7. Perform inside and outside measurements using vernier or dial calipers.
8. Perform the micrometer reading exercise outlined in the Procedures section of this module. Using an outside micrometer perform outside measurements on tubing and wire.
9. Using an inside micrometer perform inside measurements on a cylinder bore.
10. Perform cylindrical plug and ring measurements to demonstrate the use of GO-NOT GO cylindrical plug and ring gages.

MATERIALS

The following materials are suggested to support this module:

1. Steel plate machined by a nearby machine shop to have a series of holes and counter bores of nominal diameters equal to available plug gages.
2. Flanges with drilled bolt holes from nearby industries.
3. Machined shafts such as dowel pins, axles, valve stems, plug shafts, motor shafts,
4. Steel plate machined by a nearby machine shop to have threaded holes of designated sizes.
5. Flange with threaded holes.
6. Parts with threaded holes such as valve bodies and pump casings.
7. Threaded screws of the Unified System.
8. Threaded studs of the Unified System.
9. Shafts with external threads of the Unified System.
10. Steel rules or scales.
11. Dividers.
12. Calipers.
13. Vernier and Dial Calipers.
14. Micrometers.
    a. outside
    b. inside
    c. depth
    d. other (thread, disc, etc.)
15. Fixed gages.
    a. Cylindrical ring and plug gages.
    b. Threaded ring and plug gages.
16. Parts for measurement.
    a. Vee blocks.
    b. Others (drilled plate, flanges, pump parts, valve parts, etc.)

PROCEDURES

A. Procedures on the use of Dividers and Calipers

Dividers and calipers can transfer a known length from the standard to the workpiece and can transfer an unknown length from the workpiece to the standard. The following procedures allow the students/trainees to demonstrate these uses.

1. Measurement of an unknown with a divider.

   Exercises: What is the distance between lines of lined notebook paper?

   Procedure:

   a. Loosen thumb nuts to permit adjustment of the span of the dividers.
   b. Place one tip on any line of the notebook paper.
   c. Adjust span until the other tip is on an adjacent line at maximum arc radius.
   d. Tighten thumb nuts without changing the desired span.
   e. Place one tip at a unit interval of a steel scale and read the length of scale to the other tip.
   f. Repeat the above steps for other sets of lines on the notebook paper and average the results.

2. Transfer of Standard Length of a Workpiece with a divider.

   Exercise: Draw a line parallel to and four inches to the right of the left hand margin line of lined notebook paper.

   Procedure:

   a. Loosen the thumb nuts to permit adjustment of the span of the divider.
   b. Place one tip on a unit of a steel rule graduated in inches.

c. Adjust span until the other tip is on the fourth unit from the first tip.
d. Tighten thumb nuts without changing the desired span.
e. Place one tip on left hand margin line of notebook paper in the upper portion of the paper.
f. With the other tip lightly scratch an arc at a right angle and to the right of the margin line.
g. Repeat the above two steps but in the lower portion of the paper.
h. Using a straight edge, draw a line tangent to the extreme right points of the arcs.
i. Describe why the arcs were used in this solution rather than placing the divider of desired span at the intersection of the margin and any line and at the set span along the same line. (HINT: What geometrical relationship would have to exist between the margin line and the space lines?)

3. Go-No Go Measurement with Outside Calipers
Given: Cylindrical part whose outside diameter must be x as a minimum and y as a maximum. (Examples of parts that may be selected include pipe, cylindrical bar stock, tubing, conduit, cylindrical standards.)
Exercise: Is the part within tolerance?
Procedure:
a. Select two outside calipers whose span is compatible with the outside diameter limits.

b. Set on caliper to a steel rule to a span equal to x.

c. Set the other caliper to a steel rule to a span equal to y.

CAUTION: In the next step, do not force the caliper onto the outside diameter such that the span setting is altered.

d. Measurement outside diameter of the cylinder at various locations with the caliper set at x and check one of the following:
   (1) The caliper will not span the diameter at any location.
   (2) The caliper will span the diameter at least one location.
   (3) Measure the outside of the cylinder at various locations with the caliper set at y and check one of the following:
   (4) The caliper will not span the diameter at any location.
   (5) The caliper will span the diameter of at least one location.

e. Determine if the part is within tolerance from the conclusion that the x value caliper should not span an in tolerance diameter and the y value caliper should span an in tolerance diameter.

f. Check the transfer method used in this exercise:
   (1) Standard transfer to workpiece.
   (2) Unknown transfer to standard.

4. Measurement with Inside Caliper

Given: Hollow cylindrical part or drilled hole of unknown inner diameter.

Exercise: What is the value of the inner diameter?

Procedure:

a. Loosen thumb nuts of inside caliper to permit adjustment of span.

b. Place tips of caliper inside the inner diameter.

c. Adjust span of inside caliper until the tips are against diametrically opposite walls at the largest possible span. (NOTE: The student/trainee should be alert for the "feel" of the caliper. As one tip is held and the second tip is moved along the arc of the opposite wall, a shortening and lengthening of the span is noted. The most accurate measurement occurs with the longest span of the caliper.)

d. With the longest possible span, tighten the thumb nuts.

e. Place one tip of the caliper on a unit of a steel rule and read the distance of the scale from that point to the point where the other tip lies.

5. Factors Affecting the Accuracy and Precision of Dividers and Calipers

Student/trainees should relate their experiences from the above exercises to the following discussion.

a. Accuracy. Accuracy is dependent on the accuracy of the standard. If the steel rule is used as the standard, the maximum possible accuracy

is that of the steel rule. Factors affecting accuracy are primarily:

(1) Alignment of divider/caliper tips with the standard.

(2) Position of the divider/caliper relative to the standard or the workpiece. Tipping, canting, or cocking introduces error.

(3) Pressure of tips against the standard or workpiece. The "feel" is involved.

(4) Skill of the operator. Again, feel is involved as well as skills in manipulation and adjustment of thumb nuts.

(5) Cleanliness of the workpiece and instrument.

(6) Lighting level. The lighting level should offer easy readability.

b. Precision. Precision is primarily dependent on the operator. It is affected by all the sources of error discussed under accuracy.

c. Sensitivity. The sensitivity can equal that of the standard at best. It is affected by the "feel" of the divider/caliper and the discrimination of the standard.

d. Readability. Readability is that of the standard.

e. Linearity. Linearity is that of the standard except that different "feel" at different spans will affect linearity.

B. Procedures on the use of Vernier and Dial Calipers

Students/trainees should practice making measurements with vernier and dial calipers on objects supplied by the instructor. Suitable objects include veeblocks, pipe, bar stock, surplus parts, tubing. The following guidance is provided.

1. Prior to making measurements, practice loosening the set screws, moving the slide with the fine adjust, and tightening the set screws until a comfortable "feel" of the instrument is obtained.

2. To make outside measurements:
   a. Open the jaws to easily span the dimension.
   b. Hold the stationary jaw with one hand against one boundary of the dimension.
   c. With the other hand, move the slide until the movable jaw contacts the other boundary.
   d. Very lightly rock and yaw the beam while at the same time adjusting the fine adjust such that a light pressure contact is made by the jaws with both boundaries. Notice the "feel" of the device. Note that the minimum span is the most accurate measurement of the outside dimension. Note that as the minimum span is approached, the device feels rigid against the workpiece.
   e. At the minimum span, either read the measurement or tighten the set screws and carefully remove the device for reading.

3. To make inside measurements:
   a. Close the jaws to easily enter the inside dimension.
   b. Hold end of beam opposite the jaws with one hand and move the slide with the other hand until the jaws contact both boundaries.
   c. Adjust the fine adjust while very slightly rocking and yawing the beam with the other hand until a light pressure contact is made

by both jaws with the boundaries. Note that the maximum span is the most accurate measurement of the inner dimensions. Note that as the maximum span is the most accurate measurement of the inner dimensions. Note that as the maximum span is approached, the device feels rigid against the workpiece.

d. At the maximum span, either read the measurement or tighten the set screws and carefully remove the device for reading.

4. Practice in reading the vernier:
   a. Read the verniers pictured in Figure 27-2-33 to develop skill in reading vernier calipers.
   b. Check answers with the answer key sheet given on the subsequent page.

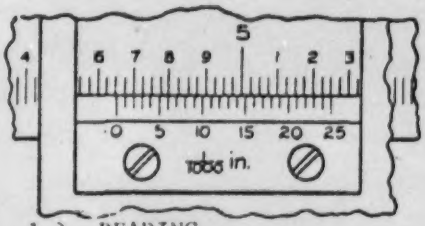
5. Repeat the vernier reading exercise with actual vernier calipers.

C. Procedures on the use of Micrometers

1. The principle of micrometer measurements is that a given rotation of a precision screw will move the spindle a predictable distance.

2. One complete revolution of the micrometer thimble moves the spindle one graduation on the barrel; therefore, the graduations on the thimble divide one barrel graduation into equal parts.

3. Micrometers without verniers have discrimination of 0.001 inch while those with verniers have discrimination of 0.0001 inch.



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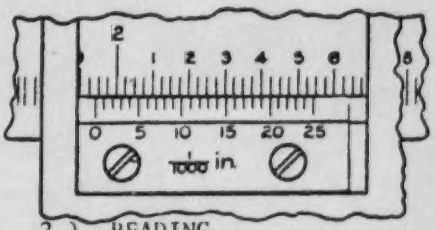
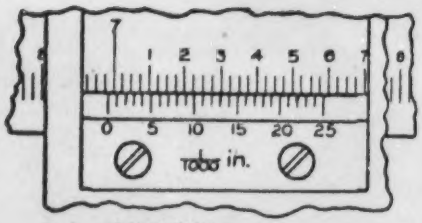


2.) READING _____



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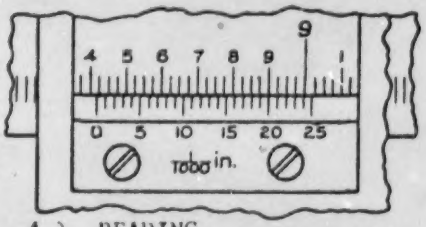
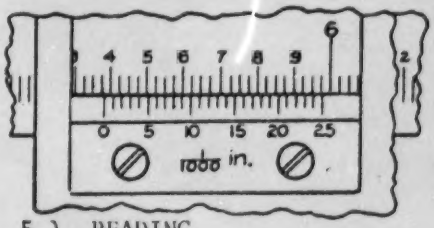


4.) READING _____



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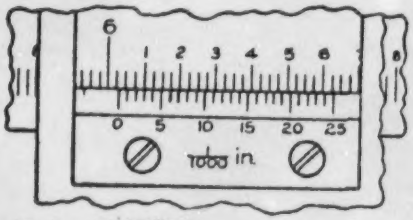

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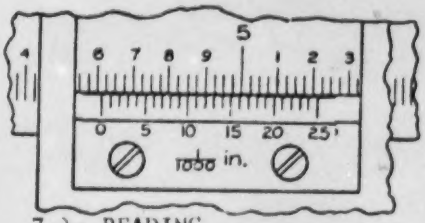

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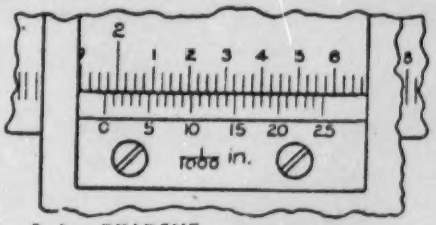

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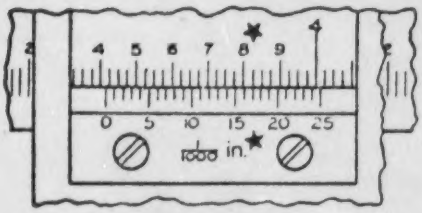

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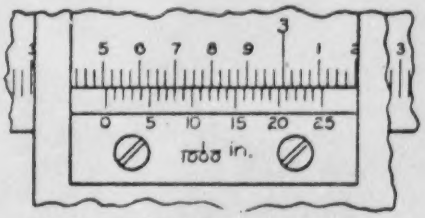

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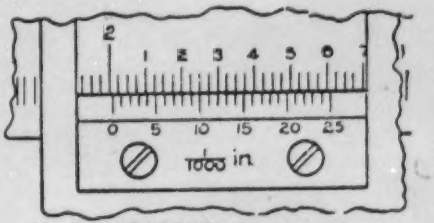

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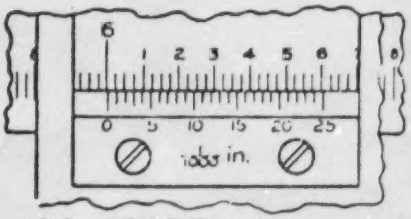
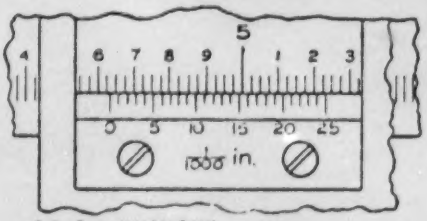
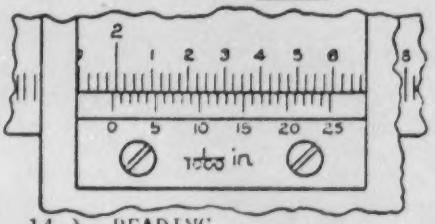


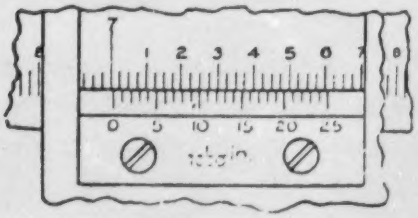
12.) READING _____



13.) READING _____



14.) READING _____



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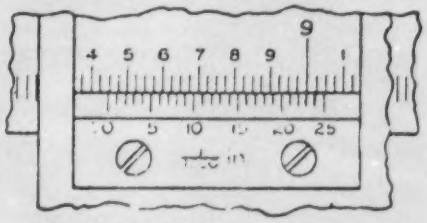

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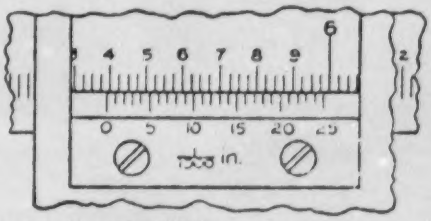

17.) READING _____

Figure 27-2-33 Vernier Reading Exercise

Answers to the Vernier Reading Exercises:

Student/trainee answers should be within ± 0.001 inch.

1. 4.652 inches
2. 1.945 inches
3. 6.987 inches
4. 8.421 inches
5. 5.383 inches
6. 6.028 inches
7. 4.612 inches
8. 1.968 inches
9. 3.417 inches
10. 2.508 inches
11. 2.011 inches
12. 6.003 inches
13. 4.633 inches
14. 1.993 inches
15. 7.010 inches
16. 8.448 inches
17. 5.338 inches

4. Many designs of micrometers are available; examples of micrometers and their applications are:

Type	Application
Outside	lengths, widths, heights, outside diameters
Inside	inside diameter, slot width
Disk	width of fins or fin-like projections
Blade	outside dimensions of grooves or recesses
Depth	depth of counter bores, non through holes
Bore (Intrimik)	holes diameters
Screw Thread	pitch diameters
Pointed Contact	dimension of recesses
Bench	outside dimension requiring great accuracy

5. Factors affecting accuracy and precision of measurements with micrometers include:
   a. spindle thread movement's accuracy, linearity, and stability
   b. flatness and parallelism of measuring surfaces
   c. deflection of frame
   d. operator alignment and contact pressure of instrument and skill in

6. Micrometer Reading Exercises
   a. Read the micrometer scales pictured on Figure 27-2-34.
   b. Check your answers with the answer key provided.

7. Repeat the micrometer reading exercise with actual micrometers.

8. Using the micrometer, perform outside measurements on tubing and wire.

9. Using an inside micrometer perform inside measurements on a cylinder bore.

D. Procedures on the use of Cylindrical Plug and Ring Gages and Thread Plug and Ring Gages

Students/trainees should be given assignments to make measurements with at least cylindrical plug and ring gages and thread plug and ring gages. If other types of fixed limit gages are available, assignments are recommended for students/trainees to make measurements with fixed cylindrical and thread gages. Alternate procedures may be used.

Read the scale of micrometers shown on this page. Try to read each scale to the nearest 0.001 inch. Check answers with the answer key.

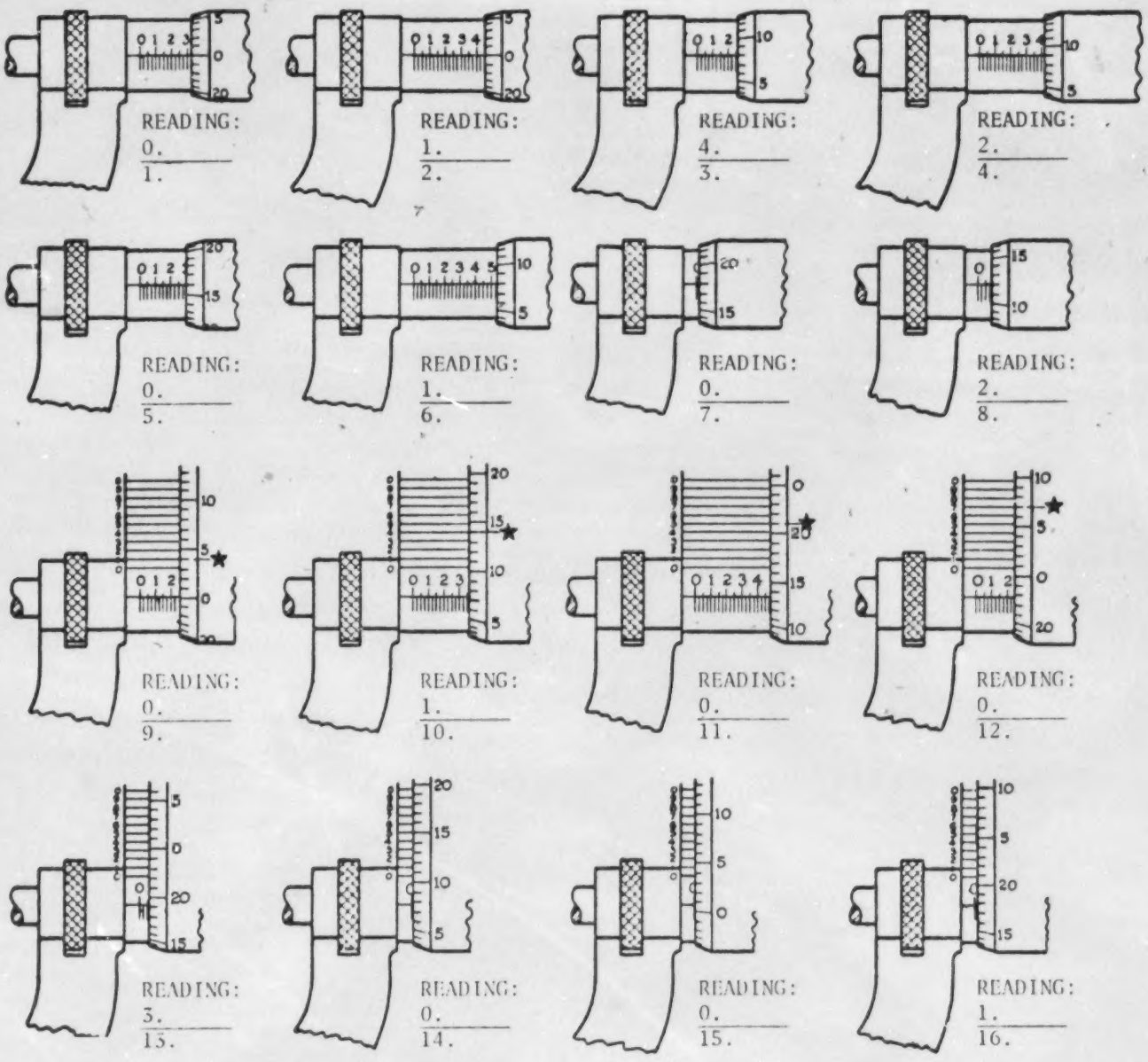

Figure 27-2-34 Micrometer Reading Exercise
(Page 1 of 2)

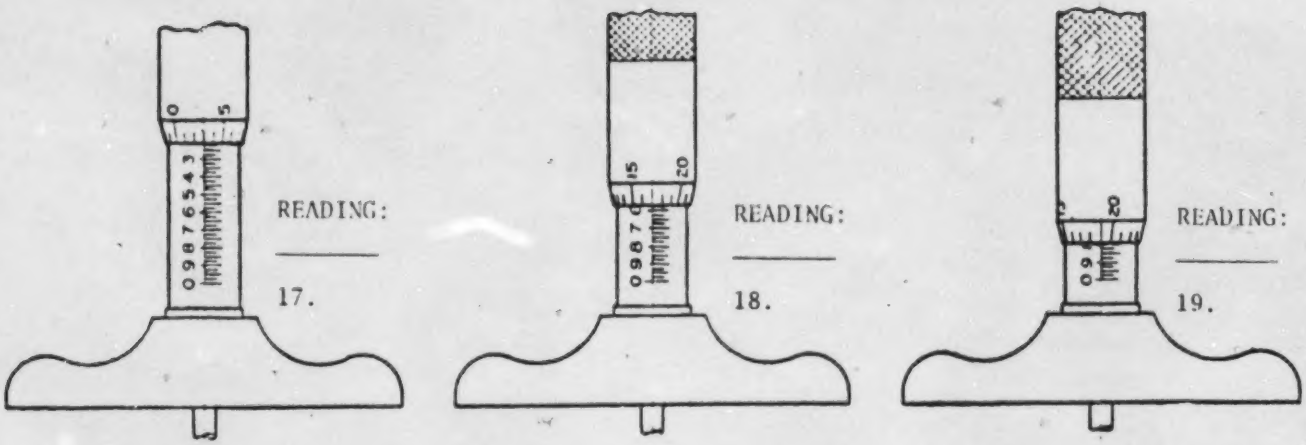

Figure 27-2-34 Micrometer Reading Exercise
(Page 2 of 2)

Answers to Micrometer Reading Exercise

1. 0.325 inch
2. 1.450 inches
3. 4.258 inches
4. 2.409 inches
5. 0.291 inche
6. 1.533 inches
7. 0.018 inch
8. 2.062 inches
9. 0.2501 inch
10. 1.3574 inches
11. 0.4635 inch
12. 0.2477 inch
13. 3.0442 inches
14. 0.0075 inch
15. 0.0006 inch
16. 1.0178 inches
17. 0.228 inch
18. 0.567 inch
19. 0.794 inch

1. Perform Cylindrical Plug Measurements

   Suggested parts for measurement:

   ___ Steel plate machined by a nearby machine shop to have a series of holes and counter bores of nominal diameters equal to available plug gages.

   ___ Flanges with drilled bolt holes from nearby industries.

   a. Using tolerances of the holes provided by the instructor, select the proper GO and NOT GO cylindrical plug gage.

   b. Clean the holes and the plug.

c. Prepare a sketch picturing the layout of the holes with respect to the part features. If the holes are not numbered, assign arbitrary numbers for identification purposes.

d. Measure each hole by determining that the GO gage enters fully and the NOT GO gage does not enter or otherwise indicate the condition that exists.

e. Record on the sketch the acceptance or rejection of each hole.

2. Perform Cylindrical Ring Measurements

Suggested parts for measurement: Machined shafts such as dowel pins, axles, valve stems, pump shafts, etc.

a. Using tolerances of the parts provided by the instructor, select the proper GO and NOT GO cylindrical ring gage.

b. Clean the parts and the gages.

c. Prepare a table consisting of these columns: (a) part number, (b) part tolerance, (c) value of GO gage, (d) value of NOT GO gage, (e) part accepted, (f) part rejected. If the parts are unnumbered, assign arbitrary numbers for identification purposes.

d. Measure each part by determining whether the part accepts the GO gage for its full length and does or does not accept the NOT GO gage.

e. Record in column (e) or (f) of the table prepared in step 4 whether the part is accepted or rejected.

3. Perform Thread Plug Measurements

Suggested parts for measurement:

___ Steel plate machined by a nearby machine shop to have threaded holes of designated sizes.

___ Flange with threaded holes.

___ Parts with threaded holes such as valve bodies and pump casings.

a. Using the thread designations provided by the instructor, select the proper GO and HI thread plug gage.

b. Clean the threaded holes and the threaded gages. (NOTE: Bottom tapped holes may cause trapped air to seize plug gages which do not have a chip groove.)

c. Prepare a sketch showing the layout of the threaded holes with respect to the part features. Show hole serial numbers or assign arbitrary identification numbers for correlation.

d. Measure each threaded hole by determining whether the GO thread gage enters entire length of the threads and the HI gage does or does not present a definite drag on or before three turns.

e. Record on the sketch whether each hole is acceptable or rejected.

4. Perform Thread Ring Measurements

Suggested parts for measurement:

___ Threaded screws for the Unified System

___ Threaded studs of the Unified System

___ Shafts with external threads of the Unified System

a. Using the thread designation provided by the instructor, select the proper thread ring gages.
b. Clean the parts and the gages.
c. If the thread ring gages are adjustable, set the GO and LO gages with a master thread plug gage provided by the instructor.
d. Prepare a table having these columns: (a) serial number of part, (b) thread designation, (c) GO thread gage identification, (d) LO thread gage identification, (e) part accepted and (f) part rejected.
e. Measure the threaded parts by determining whether the GO thread gage engages the entire length of thread and the LO thread gage presents a definite drag on or before three turns.
f. Record in column (e) or (f) of the table whether the parts is accepted or rejected.

5. Perform a comparison among rules, calipers, vernier calipers and micrometers by measuring the same dimension with each and comparing results.
   a. Select a vee-block and measure its width with each of the following instruments; record results in the accompanying Data Table.
      - steel rule
      - outside caliper with the steel rule as the standard
      - vernier caliper
      - outside micrometer
   b. If the steel rule is graduated in fractions, convert the measurements of the rule and caliper to a decimal and record on the accompanying

Data Table. (See conversion table appended to this procedure.)

c. Obtain from the instructor the true value of the width of the vee-block.

d. Determine the relative accuracy and discrimination of the four instruments and place numerical ranking values in columns (2) and (5) of the Data Table where 1 is most accurate or has best discrimination and 4 is least.

e. Compare your measured values with those of another student/trainee in column (4) of the Data Table, state your opinion of the rationale of any differences in measured values. If you both have identical values, state "same" in column (4).

DATA TABLE

MEASUREMENT OF VEE BLOCK WIDTH				
	MEASURED VALUE (1)	RELATIVE RANKING		COMPARISON WITH ANOTHER STUDENT/TRAINEE MEASURED VALUES; RATIONALE FOR DIFFERENCES (4)
		ACCURACY (2)	DISCRIMINATION (3)	
Steel Rule				
Outside Caliper				
Vernier Caliper				
Micrometer				
True Value Provided by Instructor				

This conversion table is provided for the convenience of the student/trainee for any laboratory work requiring conversion of decimals to fractions and vice-versa.

DECIMAL EQUIVALENTS

1/64	.015625
1/32	.03125
3/64	.046875
1/16	.0625
5/64	.078125
3/32	.09375
7/64	.109375
1/8	.125
9/64	.140625
5/32	.15625
11/64	.171875
3/16	.1875
13/64	.203125
7/32	.21875
15/64	.234375
1/4	.25
17/64	.265625
9/32	.28125
19/64	.296875
5/16	.3125
21/64	.328125
11/32	.34375
23/64	.359375
3/8	.375
25/64	.390625
13/32	.40625
27/64	.421875
7/16	.4375
29/64	.453125
15/32	.46875
31/64	.484375
1/2	.5
33/64	.515625
17/32	.53125
35/64	.546875
9/16	.5625
37/64	.578125
19/32	.59375
39/64	.609375
5/8	.625
41/64	.640625
21/32	.65625
43/64	.671875
11/16	.6875
45/64	.703125
23/32	.71875
47/64	.734375
3/4	.75
49/64	.765625
25/32	.78125
51/64	.796875
13/16	.8125
53/64	.828125
27/32	.84375
55/64	.859375
7/8	.875
57/64	.890625
29/32	.90625
59/64	.921875
15/16	.9375
61/64	.953125
31/32	.96875
63/64	.984375
1	1.

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ANSI Y14.6, Screw Threads, American National Standards Institute, New York, New York.

ANSI B1.1, Unified Inch Screw Threads, American National Standards Institute, New York New York.

TEST

Read each question carefully. Be sure to provide the specific information each question requires. Make your answers brief. Use the backs of the test if you need more space.

1. Define GO GAGE._____

2. Define NOT GO GAGE._____

3. Name one typical use of each of the following gages:
   a. cylindrical plug gage_____
   b. cylindrical ring gage_____
   c. thread plug gage_____
   d. limit snap gage_____

4. Name three error sources common to all fixed limit gages.

5. Describe the difference between a master fixed gage and a limit fixed gage.

_____

_____

_____

_____

_____

_____

6. In the thread designation .250-20 UNF-1B, what is represented by each of the following:

a. .250_____

b. 20_____

c. F_____

d. B_____

7. Name one typical use of each of the following:

a. slide caliper_____

b. vernier caliper_____

c. outside micrometer_____

d. inside micrometer_____

8. Name three error sources associated with the major vernier caliper.

_____

_____

_____

_____

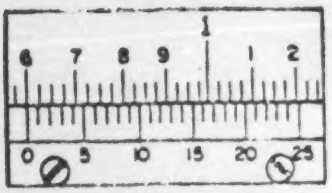
_____

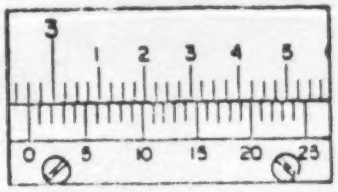
_____

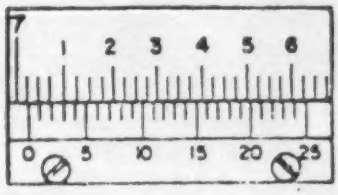
_____

_____

9. Give the reading of the following vernier scales:







a. Reading_____ b. Reading_____ c. Reading_____

10. Name three error sources associated with the outside micrometer.

_____

_____

_____

_____

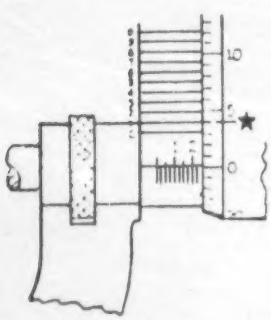
_____

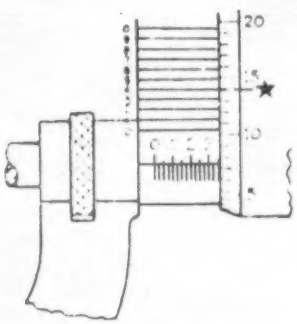
_____

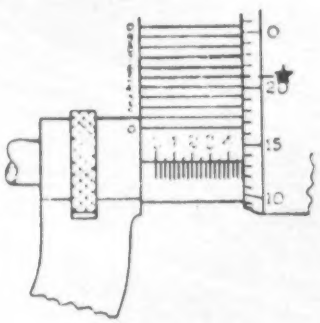
_____

_____

11. Give the reading of the following micrometer scales:







a. Reading_____ b. Reading_____ c. Reading_____

12. Describe how to measure an outside length dimension with a vernier caliper by listing five steps in proper sequence for making the measurement.

a. _____

b. _____

c. _____

d. _____

e. _____